Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 4 (2011) 4307–4313

Energy Procedia

www.elsevier.com/locate/procedia

GHGT-10

Carbon Dioxide Microbubble Injection – Enhanced Dissolution in Geological Sequestration

Ziqiu Xue[a]1*, Tatsuya Yamada[b], Toshifumi Matsuoka[b], Hiromichi Kameyama[c], Susumu Nishio[c]

[a] *Research Institute of Innovative Technology for the Earth (RITE), 9-2 Kizugawadai, Kizugawa, Kyoto, 619-0292, Japan*
[b] *Dept. of Civil and Earth Resources Engineering, Kyoto University, Nishikyo-ku, Kyoto, 615-8540, Japan*
[c] *Technology Research Institute, Tokyo Gas Co., Ltd., Tsurumi-ku, Yokohama, Kanagawa, 230-0045, Japan*

Abstract

CO_2 microbubble injection is a novel technology for geological sequestration. Currently most of CO_2 geological sequestration projects are focused on large-scale emission sources, while there is a practical need to inject CO_2 from small- to middle- scale emission sources. CO_2 microbubble injection is available for storing CO_2 in aquifers with non-anticline (monotonic) structure in a low-cost concept. In this study CO_2 microbubbles were generated by injecting CO_2 through micro porous filters and the behaviors of CO_2 microbubbles were recorded by a high speed video camera system. Our results suggest that more microbubbles generated by filters with smaller pore and CO_2 dissolution enhanced by CO_2 microbubbles. CO_2 microbubble injection provides an option of considering monoclinic structures exist widely in Japan, as useful sites. We are working on quantifying the CO_2 microbubbles size and the volume of dissolved CO_2 in saline aquifers.

Keywords: carbon dioxide, microbubble, porous filter, dissolution, aquifer, geological sequestration

1. Introduction

CO_2 geological sequestration is one of the most promising technologies for reducing greenhouse gas emission. There are many pilot- and commercial-scale projects of CO_2 geological sequestration under planning or in operation. To secure safety of CO_2 injection into saline aquifers, CO_2 is expected to be stored in geological formations with anticline structures similar to oil and gas reservoirs. In Japan large scale injection sites such as Sleipner (North Sea) are limited and these sites are not always close to CO_2 emission sources. Such mismatching of CO_2 source and sink usually causes cost escalation in transportation and storage. CO_2 microbubble injection provides an option of injecting CO_2 into monoclinic structures exist widely in Japan, as useful storage sites. Previous studies suggest that CO_2 microbubble accelerates dissolution of CO_2 into formation water (Shimoda et al., 1998; Kobayashi et al., 2007) and dissolved CO_2 will be fixed stably in saline aquifers (Koide and Xue, 2008). This method may enable CO_2

* Corresponding author. Tel.: +81-774-75-2312; fax:+81-774-75-2314.
E-mail address: xue@rite.or.jp.

doi:10.1016/j.egypro.2011.02.381

geological sequestration to the storage sites with monoclinic structure widely distributed in Japan. Additionally, small-scale CO_2 sequestration from hydrogen filling stations, will become available for the coming hydrogen energy society.

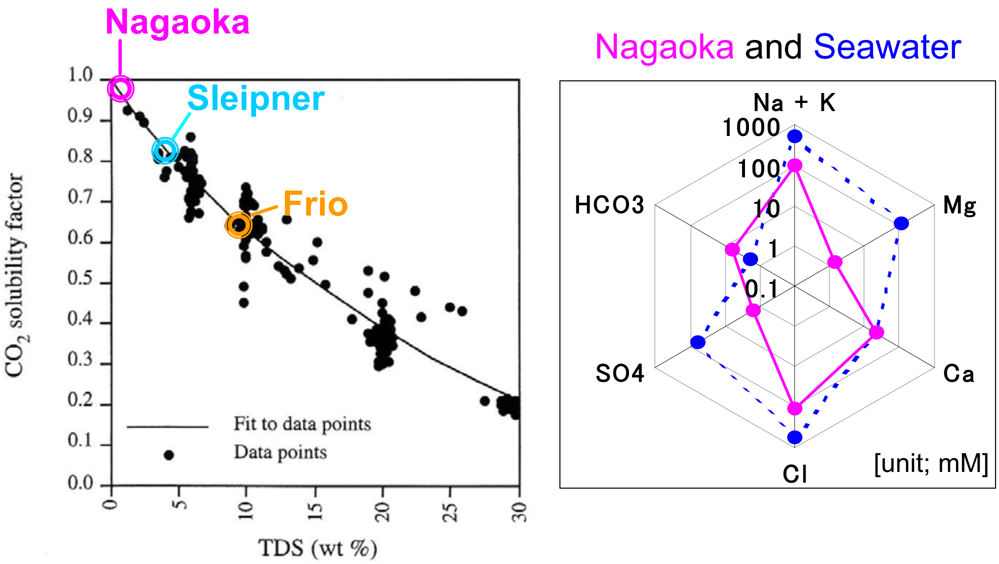


Figure 1 Water composition at the Nagaoka pilot site (Mito et al, 2008)

Injection of CO_2 into the pore space of a permeable formation can displace the in situ fluid or the CO_2 may dissolve in or mix with the fluid or react with the mineral grains or there may be some combination of these processes. At the Nagaoka site the formation fluid was sampled by Cased Hole Dynamics Tester (CHDT) at one of the three observation wells where data from well loggings have revealed the occurrence of CO_2 breakthrough (Mito et al., 2007). Results of chemical analyses showed the high HCO_3^-concentration compared to original formation water. The formation water sampling point was just under the CO_2-bearing zone.

Numerical studies for a CO_2 injection into a deep aquifer showed that a significant amount of CO_2 (up to 29 % of the total injected amount) would dissolve into formation water (solubility trapping) over the life time of the injection operation (Bachu et al., 1994). Dissolution of CO_2 into formation water depends on formation pressure, temperature and salinity. In comparison to Sleipner and Frio, Nagaoka site shows a large potential of CO_2 dissolution, due to the low salinity of formation water (Figure 1). Japanese reservoirs also have a big advantage for mineral trapping of CO_2, due to the complex mineral compositions and reactive minerals (Figure 2).

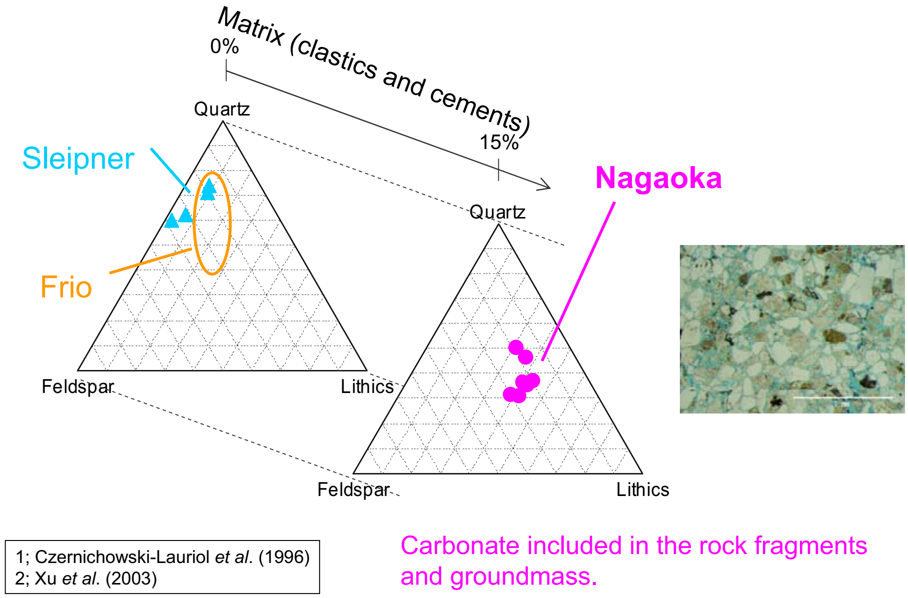


Figure 2 Composition of reservoir rocks (Mito et al, 2008)

2. Experimental Procedure

Microbubble technology has been used in many fields, such as sterilization or cleaning. Figure 3 shows several methods for generating microbubbles. In selecting the method for generating CO_2 microbubbles, there are some points to be followed for practical use at deep saline aquifers, such as easy installation and low cost. Finally we decided to inject CO_2 through a micro porous filter. In this study, stainless and grind stone filters were used to generate CO_2 microbubbles.

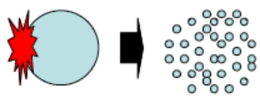
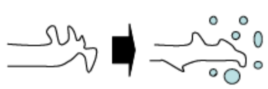
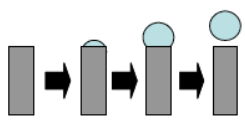
image	name	bubble diameter
	crush (shock wave)	<10 μm
	shear flow	20 μm～1mm
	micro porous	20 μm～1cm

Figure 3 methods of generating microbubbles

Figure 4 shows a schematic view of the whole experimental apparatus. A high pressure vessel with attached silicon rubber heater was used to simulate pressure and temperature conditions in deep saline aquifers. CO_2 can be injected in gaseous, liquid and supercritical phases, depending on pressure and temperature conditions. Two syringe pumps were used to control CO_2 injection pressure and pore pressure inside the vessel. There are two observation windows located at the middle of the pressure vessel for observation of CO_2 microbubbles generated from the porous filter. A high speed video camera system was used to record behaviors of CO_2 microbubbles discharged from micro filters during the observation experiments.

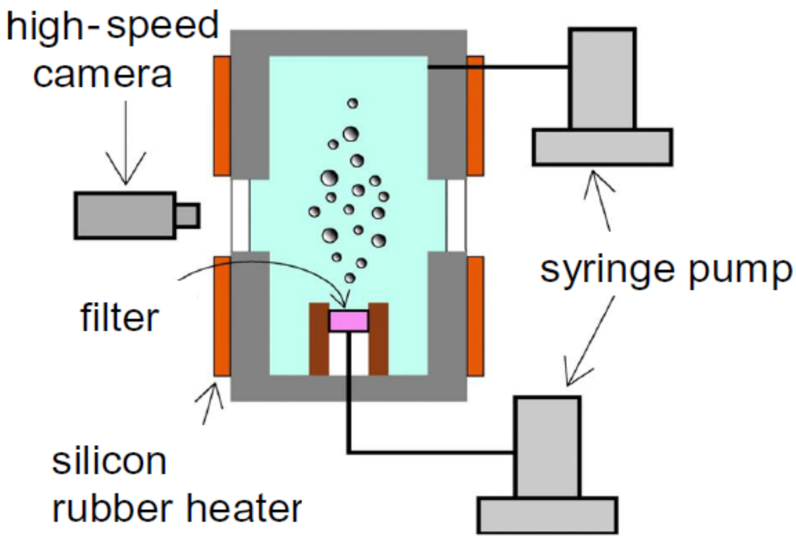


Figure 4 The experimental apparatus

3. Experimental Results

Three filters were used to generate CO_2 microbubbles in the observation experiments. Figure 5 shows the scanning electron microscope (SEM) images of one stainless and two grind stone filters. The main differences among of the three filters are pore size and its distribution. In this study effects on CO_2 microbubble generation of the filters were analyzed by image processing.

Figure 6 shows the experimental results when injecting supercritical CO_2 through stainless and grind stone filters. The pore pressure was 10 MPa and the temperature was 40 degree C. The rate for CO_2 injection was 10 ml/min and the CO_2 injection pressure was a little higher than 10 MPa. In the case of stainless filter there were several streams of CO_2 microbubbles formed in limited area. In comparison to stainless filter, the two grind stones generated much more CO_2 microbubbles from the whole surfaces. The blue grind stone having smaller pore size than the white one showed advantages in microbubble generation. Such results indicate that pore size and its distribution have significant effects on CO_2 microbubble generation.

Figure 7 shows dissolution of CO_2 microbubble generated from the stainless filter. A big bubble, its diameter is larger than 1 cm, moved upward almost constantly. One stream of CO_2 microbubbles dissolved at a particular distance from the filter. These results indicate microbubbles have less buoyant force compared to big bubbles and dissolve into formation water quickly. Figure 8 shows the result of enhanced dissolution of CO_2 microbubble. The enhanced effect for dissolution is about 20% estimated from image processing.

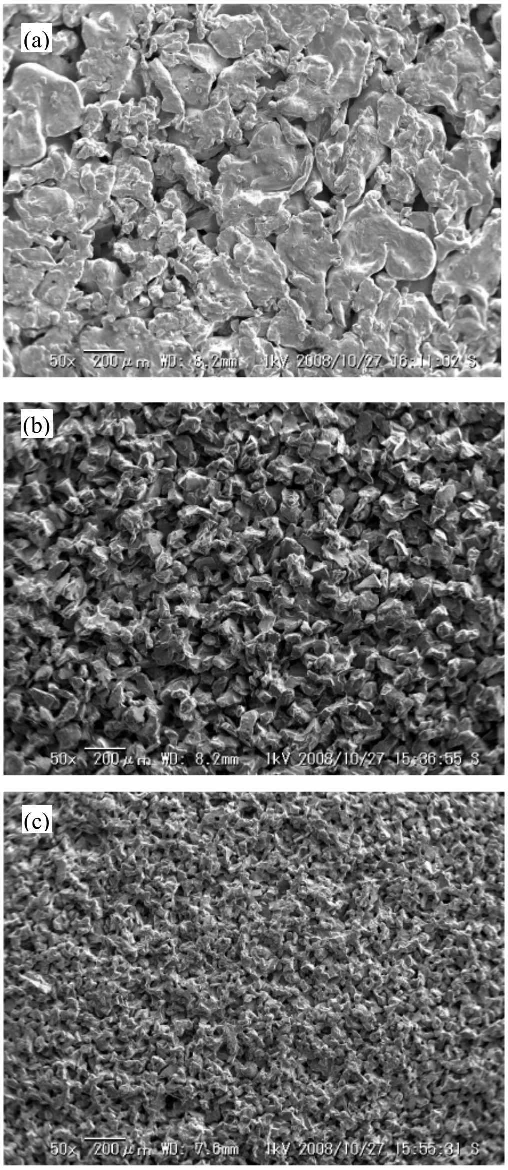


Figure 5 SEM images of filters (1.7mm×2.5mm).(a)stainless,(b)white grind stone,(c)blue grind stone

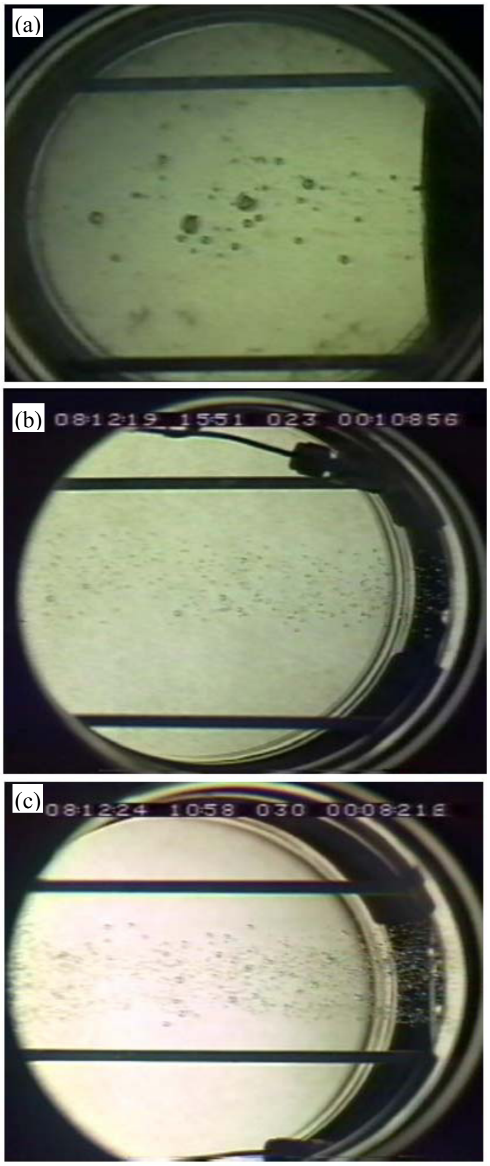


Figure 6 Supercritical CO_2 microbubbles generated from (a)stainless, (b)white grind stone, (c)blue grind stone

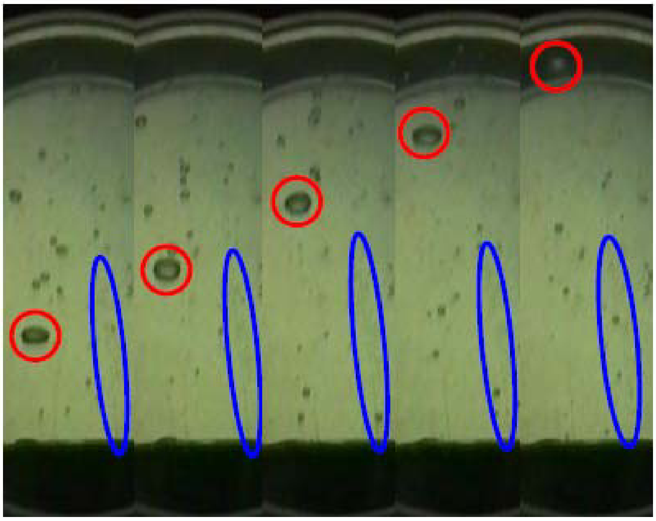


Figure 7 Dissolution of CO_2 micronbubbles (Time step is 0.1 sec for each image)

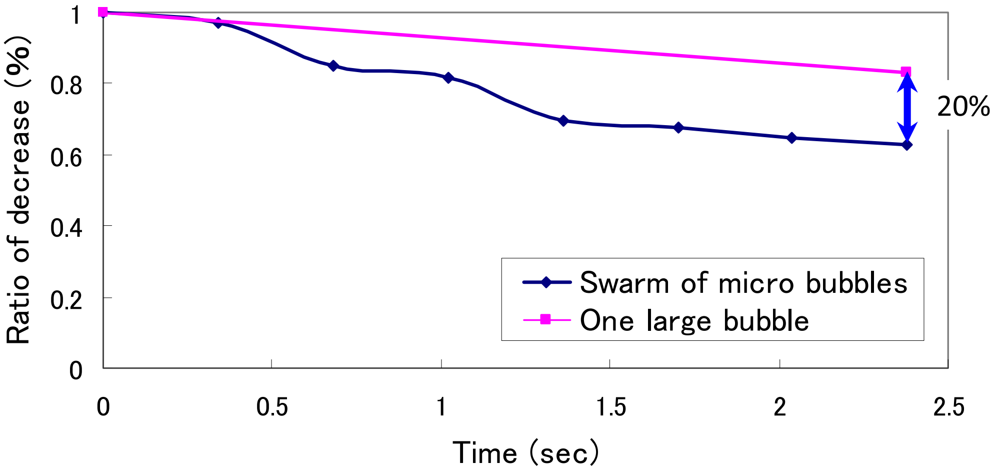


Figure 8 Enhanced effect of microbubble CO_2 dissolution

4. Conclusions

A series of experimental study on CO_2 microbubble generation with different porous filters was carried out to improve understanding of the generation mechanism of CO2 microbubbles. Pore size of a filter is an important factor when generating CO2 microbubbles. Enhanced effects of dissolution were confirmed from image processing and this result indicates the capability of CO2 microbubble geological sequestration. For the Future work, evaluation of volumes of CO_2 microbubbles dissolved in formation water and CO_2 microbubble monitoring injected into sandstones are underway. The flexibility of CO_2 microbubble sequestration enables the source-sink matching much easier than the conventional CO_2 storage practices. In the near future of hydrogen society CO_2 microbubble sequestration is expected as a practically energy-saving and cost-effective greenhouse gas reduction technology.

5. References

Bachu, S., Gunter, W.E., Perkins, E.H., 1994. Aquifer disposal of CO_2 : Hydrodynamic and mineral trapping. Energy Convers. Manag. 35, 269-279.

Kobayashi,F., Hayata,Y., Muto,N., Osajima,Y. (2007): Effect of the pore size of microfilters in supercritical CO_2 bubbling on the dissolved CO_2 concentration. Food Sci. Technol. Res., 13(2), 2007, 118-120

Koide,H., Xue,Z. (2008): Carbon microbubbles sequestration : a novel technology for stable underground emplacement of greenhouse gases into wide variety of saline aquifers, fractured rocks and tight reservoirs. Energy Procedia 2009, 3655-3662

Mito S., Xue Z., Ohsumi T., 2008, Case study of geochemical reactions at the Nagaoka CO_2 injection site, Japan. International Journal of Greenhouse Gas Control, 2(3), 309-318.

Shimoda,M.,Yamamoto.,Y,Cocunubo-Castellanos,J., Tonoike,H., Kawano,T., Ishikawa,H., and Osajima,Y(1998): Antimicrobial effects of pressured carbon dioxide in a continuous flow system. J. Food Sci.63 (4) 1998, 709-712

PCT: WO 2010/018844 A1, Storing device for stored substance and method for storing stored substance.